

# **CORRECTION OF THIN CIRRUS EFFECTS IN AVIRIS IMAGES USING THE SENSITIVE 1.375- $\mu$ m CIRRUS DETECTING CHANNEL**

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## **1. INTRODUCTION**

Using spectral imaging data acquired with the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) from an ER-2 aircraft at 20 km altitude during various field programs, it was found that narrow channels near the center of the strong 1.38- $\mu$ m water vapor band are very effective in detecting thin cirrus clouds (Gao et al., 1993). Based on this observation from AVIRIS data, Gao and Kaufman (1994) proposed to put a channel centered at 1.375  $\mu$ m with a width of 30 nm on the Moderate Resolution Imaging Spectrometer (MODIS) (Salomonson et al., 1989) for remote sensing of cirrus clouds from space. The sensitivity of the 1.375- $\mu$ m MODIS channel to detect thin cirrus clouds during the day time is expected to be one to two orders of magnitude better than the current infrared emission techniques. As a result, much larger fraction of the satellite data is expected to be identified as being covered by cirrus clouds; some of them so thin that their obscuration of the surface is very small. In order to make better studies of surface reflectance properties, thin cirrus effects must be removed from satellite images. Therefore, there is a need to study radiative properties of thin cirrus clouds, so that a strategy for correction or removal of the thin cirrus effects, similar to the correction of atmospheric aerosol effect (e.g., Kaufman and Sendra, 1988), can be formed. In this extended abstract, we describe an empirical approach for removing/correcting thin cirrus effects in AVIRIS images using channels near 1.375  $\mu$ m - one step beyond the detection of cirrus clouds using these channels.

## **2. BACKGROUND**

Cirrus clouds consist of ice particles having different sizes and shapes. The "effective" particle sizes are usually greater than 5  $\mu$ m. We illustrate the scattering and absorption properties of cirrus clouds through examples. Figure 1 shows two AVIRIS spectra (in reflectance units) acquired over areas covered by thick and thin cirrus clouds above Monterey Bay in California on September 4, 1992. The spectra below 0.5  $\mu$ m are not shown here due to calibration problems. For each spectrum, the reflectances of ice particles in the 0.5 - 1.1  $\mu$ m spectral region are constant with wavelength, because ice particle sizes are much greater than wavelengths. The larger apparent reflectances in the 0.5 - 0.6  $\mu$ m region are due to Rayleigh scattering. Beyond 1.1  $\mu$ m, ice absorption effects, for example the ice bands centered near 1.5 and 2.0  $\mu$ m, are seen in the two spectra. The ice absorption effects near 1.24  $\mu$ m are weak. Near 1.375  $\mu$ m, both water vapor and ice particles have absorptions. The ice absorption effects near 1.375  $\mu$ m are comparable to those near 1.24  $\mu$ m, because imaginary parts of ice refractive indices at both wavelengths are about the same.

At present, accurate modeling of cirrus scattering and absorption effects is still very difficult. Our knowledge on cirrus particle size distributions and optical properties are not sufficient (King, 1993). Cirrus spatial inhomogeneity and adjacency effects are also difficult to be treated properly in radiative transfer models. In view of these difficulties, we propose to establish empirical relationships among remote sensing measures to characterize the main cirrus properties, and then to develop an empirical cirrus correction/removal technique.

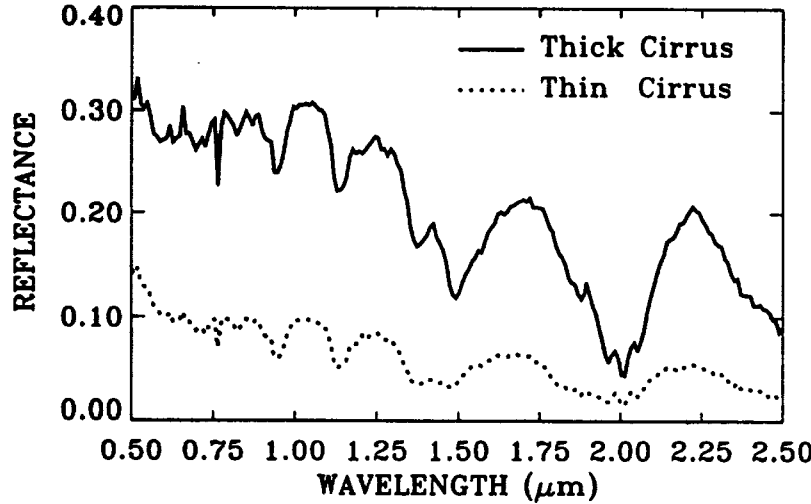


Fig. 1. Examples of AVIRIS spectra over thick and thin cirrus clouds.

### 3. THE EMPIRICAL APPROACH

For thin cirrus clouds, we assume that a homogeneous thin cirrus layer is located above a virtual "surface", which includes the effects of Rayleigh scattering and bottom surface reflection and scattering. With these assumptions, we have the following relationship (similar to descriptions of aerosol scattering, e.g., Fraser and Kaufman, 1985):

$$\rho_{\lambda}^* = \rho_{c\lambda} + T_{c\lambda} \rho_{\lambda} / (1 + S_{c\lambda} \rho_{\lambda}) \quad (1)$$

where  $\rho_{\lambda}^*$  is the measured spectral radiance (normalized to reflectance units),  $\rho_{\lambda}$  is the reflectance of the virtual "surface",  $\rho_{c\lambda}$  is the atmospheric path radiance due to the cirrus cloud (radiation backscattered by the cloud),  $T_{c\lambda}$  is the two way transmission (direct + diffuse) through the cloud, and  $S_{c\lambda}$  is the cloud scattering of upward radiation back to the surface.  $S_{c\lambda} \rho_{\lambda} \ll 1$  for thin cirrus, and Eq. (1) can be simplified to:

$$\rho_{\lambda}^* = \rho_{c\lambda} + T_{c\lambda} \rho_{\lambda} \quad (2)$$

In order to correct  $\rho_{\lambda}^*$  for the cirrus effect, namely to derive  $\rho_{\lambda}$  based on Eq. (2), cirrus path radiance  $\rho_{c\lambda}$  and transmittance  $T_{c\lambda}$  must be known.

Analyzing AVIRIS data, we have found that cirrus path radiances  $\rho_{c\lambda}$  for AVIRIS channels between 0.4 and 1.1  $\mu\text{m}$  are linearly related to  $\rho_{c\ 1.375\ \mu\text{m}}$ ,

$$\rho_{c\lambda} = \rho_{c\ 1.375\ \mu\text{m}} / t_{CO} \quad (3)$$

where  $t_{CO}$  is less than 1 due to ice and water vapor absorption at 1.375  $\mu\text{m}$  and can be derived from AVIRIS data themselves. For thin cirrus clouds,  $T_{c\lambda}$  is usually greater than 0.9. Correction of cirrus path radiances can be made relatively easily. Substitute Eq. (3) into Eq. (2), we obtain:

$$T_{c\lambda} \rho_{\lambda} = \rho_{\lambda}^* - \rho_{c\ 1.375\ \mu\text{m}} / t_{CO} \quad (4)$$

Images of  $T_{c\lambda} \rho_{\lambda}$  are cirrus path radiance corrected images. Because of the large transmittance of thin cirrus, images of  $T_{c\lambda} \rho_{\lambda}$  are very similar to images of  $\rho_{\lambda}$ .

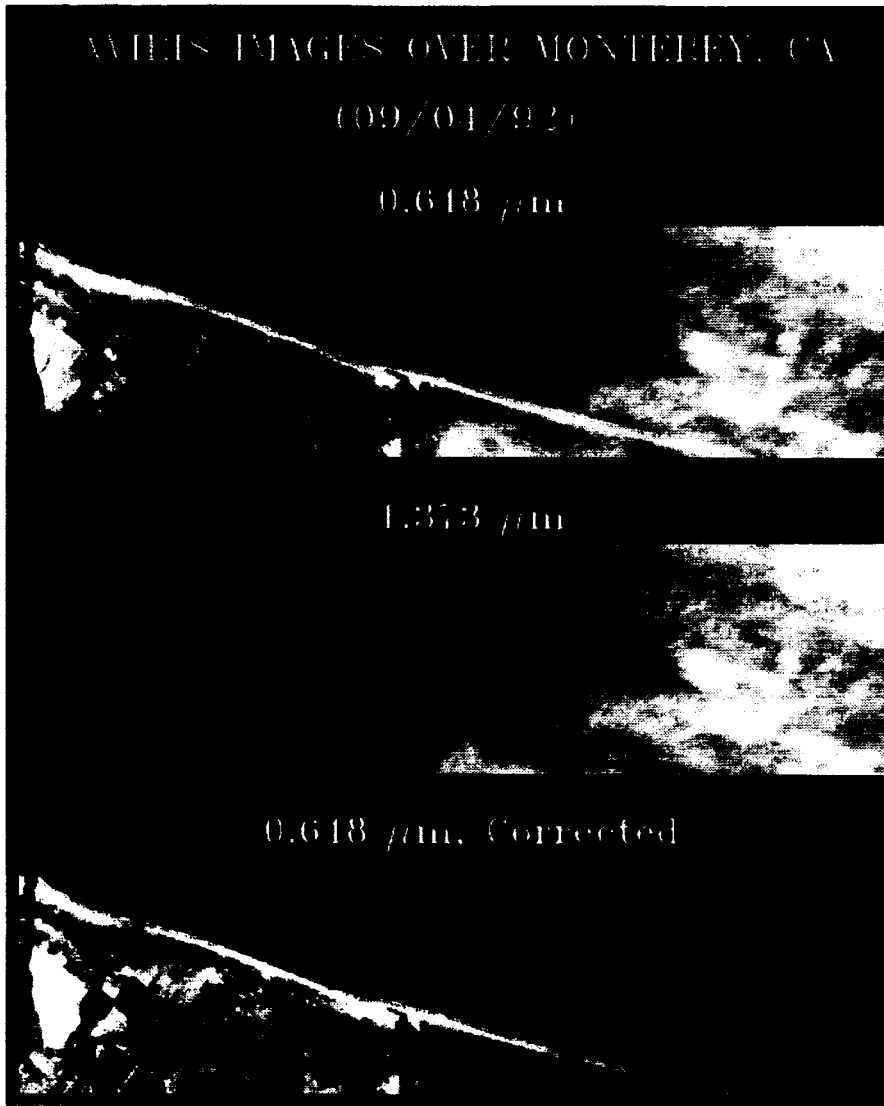


Fig. 2. A 0.648  $\mu\text{m}$  AVIRIS image (top plot), 1.373  $\mu\text{m}$  image (middle plot), and cirrus path radiance corrected 0.648  $\mu\text{m}$  image (bottom plot).

Corrections of the cirrus transmittances  $T_{c\lambda}$  are practically more difficult than the corrections of path radiances. The solar radiation on the two-way path (Sun-cirrus-surface-cirrus-sensor) encounters cirrus clouds at different spatial locations. Due to the non-local nature of  $T_{c\lambda}$ , it is difficult to make accurate derivation of  $T_{c\lambda}$  from AVIRIS images. Nevertheless, we are making progress in deriving a quantity from AVIRIS images that would characterize the main properties of  $T_{c\lambda}$ .

#### 4. RESULTS AND DISCUSSION

Figure 2 shows an example of our correction of thin cirrus effects. The top plot shows the 0.648- $\mu\text{m}$  image. The image was acquired over Monterey, CA on September 4, 1992. The image covers both land and ocean areas. A number of land surface features are blurred due to the presence of thin cirrus clouds. The middle plot of Fig. 2 shows the 1.373- $\mu\text{m}$  image over the same area. Only cirrus clouds are seen. Fig. 3 shows a scatter plot of  $\rho^*_{1.373\mu\text{m}}$  versus  $\rho^*_{1.043\mu\text{m}}$  for many pixels over the ocean. The straight line

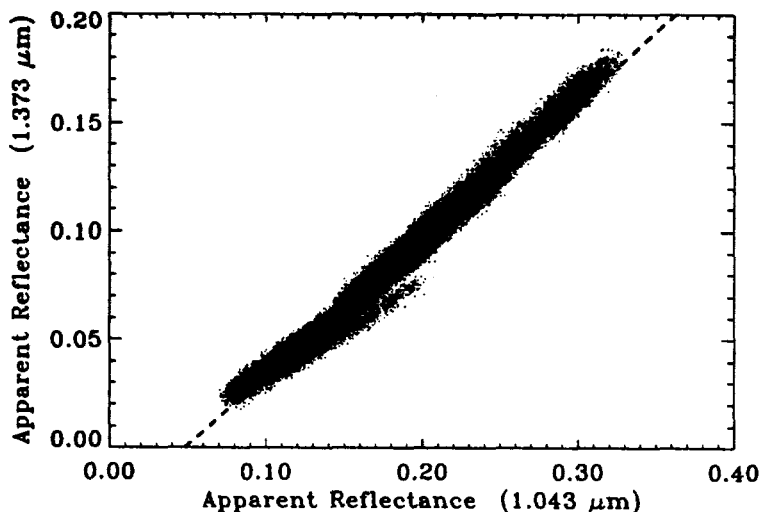


Fig. 3. A scatter plot of apparent reflectances at 1.373  $\mu\text{m}$  vs those at 1.043  $\mu\text{m}$ .

is a linear fit to all the points. The slope, 0.635, of the fitted line can be considered as good estimate of  $t_{\text{CO}}$  (see Eq. 3). The bottom plot of Fig. 2 shows our path radiance corrected image. Most of the cirrus clouds over the ocean are removed. Land features are far less blurred than those in the top plot.

As expected, the AVIRIS images in Figure 2 were contaminated by stratospheric aerosols resulted from Mt. Pinatubo volcano eruption in 1991. As a result, the minimum reflectance of the 1.373- $\mu\text{m}$  is about 0.02, not zero.

## 5. SUMMARY

We have developed an empirical technique that is successful in removing the cirrus path radiances in AVIRIS images between 0.4 and 1.1  $\mu\text{m}$ . The derivation of two-way cirrus transmittance factor is more difficult because of the non-local nature of the two-way transmittance. *The authors would like to express appreciation to J. Von Den Bosch of Jet Propulsion Laboratory for providing the AVIRIS data used in this study.*

## 6. REFERENCES

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